REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
Mar 2010		

4. TITLE AND SUBTITLE

Low-Cost Navigation Sensors
and Integration Technology
(Capteurs de navigation à faible coût et technologie d'intégration)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Research and Technology Organisation (NATO)
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

RTO-EN-SET-116

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release

13. SUPPLEMENTARY NOTES

Supporting documents are attached to the report as separate files (PDF, HTM).

14. ABSTRACT

This Lecture Series presented the current state-of-the-art in navigation sensors and system integration technology through the improved use of advanced, low-cost navigation sensor technologies. The material presented provided an understanding of the issues faced by today's system designers. Through this Lecture Series, the technical community was updated on sensors and current integration techniques as practiced by leading experts in the field. The Lecture Series included information to bring the audience up-to-date with current practices, as well as, information on sensors, algorithms, and applications. Applications were described for navigating in difficult urban, indoor, and underground environments where typical GPS receivers do not function.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U	SAR	5	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

AC/323(SET-116)TP/311

www.rto.nato.int

RTO EDUCATIONAL NOTES **EN-SET-116(2010)**

Low-Cost Navigation Sensors and Integration Technology

(Capteurs de navigation à faible coût et technologie d'intégration)

The material in this publication was assembled to support a Lecture Series under the sponsorship of the Sensors and Electronics Technology Panel (SET) on 15-16 March 2010 in Ankara, Turkey; on 18-19 March 2010 in Prague, Czech Republic; 22-13 March 2010 in Toulouse, France and on 25-26 March 2010 in Porto, Portugal.

Published March 2010

The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

Published March 2010

ISBN 978-92-837-0109-5

Low-Cost Navigation Sensors and Integration Technology

(RTO-EN-SET-116-2010)

Executive Summary

The objective of this two-day Lecture Series is to present the current state-of-the-art in navigation sensors and system integration technology through the improved use of advanced, low-cost navigation sensor technologies. Lecturers will present material that provides an understanding of the issues faced by today's system designers. Through this Lecture Series, the technical community will be updated on sensors and current integration techniques as practiced by leading experts in the field. The Lecture Series includes information to bring the audience up-to-date with current practices, as well as, information on sensors, algorithms, and applications. Technology trends are described for navigating in difficult urban, indoor, and underground environments where typical GPS receivers do not function.

The first day begins with an overview paper that focuses on accuracy and other technology trends for inertial sensors, Global Positioning Systems (GPS), and integrated strapdown Inertial Navigation System (INS/GPS) systems that will lead to better than 1-meter accuracy navigation systems of the future. The paper provides the rationale for the remaining papers. The second paper starts with a brief overview of inertial sensing and the technology trends underway. Discussions are presented on gyro and accelerometer technology development, with specific emphasis on designs and performance of Ring Laser Gyros, Fiber Optic Gyros, and MEMS sensors. The third paper discusses MEMS in depth. The specific advantage of MEMS in ruggedness and size is demonstrated with reference to specific applications, such as guided munitions. A precise kinematic relative positioning system using a stand-alone miniaturized L1 GPS data logger is described in the fourth paper. The fifth paper focuses on INS/GPS integration architectures including "loosely coupled", "tightly coupled", and "deeply integrated" configurations. The advantages and disadvantages of each level of integration are discussed. In the sixth and final paper of the first day, the three major INS/GPS systems architectures discussed in the previous paper will have their performance compared for various mission scenarios.

The second day of the Lecture Series focuses on applications involving limited GPS availability. The first paper discusses some of the ongoing activities in the technology development of small inertial navigation sensors and augmentation sensors that could be used to improve performance in applications with little or no GPS signal. The second paper focuses on the latest technology trends for navigating in difficult urban, indoor, and underground environments where typical GPS receivers do not function. Alternative navigation technologies based on electro-optical techniques will be described. These include optically aided and ladar-aided INS. The last paper focuses on multi-sensor fusion for navigation in difficult environments. A generic multi-sensor fusion approach is presented and simulation and experimental results are presented.

Les capteurs de navigation à bas coût et la technologie d'intégration

(RTO-EN-SET-116-2010)

Synthèse

L'objectif de cette Suite de Conférences de deux jours était de présenter l'état de l'art en matière de capteurs de navigation et de technologie d'intégration des systèmes avec une meilleure utilisation de technologies évoluées et à bas coût de capteurs de navigation. Les conférenciers ont présenté le matériel qui permettait de comprendre les problèmes auxquels sont confrontés les concepteurs actuels des systèmes. A travers cette suite de conférences, la communauté technique a reçu une mise à jour sur les capteurs et les techniques d'intégration actuelles telles qu'elles sont pratiquées par les meilleurs experts du domaine. La Suite de Conférences comprenait des travaux dirigés afin que les auditeurs soient informés sur les pratiques actuelles mais aussi sur les capteurs et leurs applications. Des orientations technologiques ont été décrites pour la navigation souterraine, pratiquée en intérieur ou en milieu urbain difficile, là où les récepteurs GPS classiques ne fonctionnent pas.

Le premier jour a commencé par une vue d'ensemble mettant l'accent sur la précision et les autres orientations technologiques pour les capteurs inertiels, le Global Positioning Systems (GPS) et les Systèmes de Navigation Inertiels intégrés (INS/GPS) qui porteront la précision des systèmes de navigation futurs à moins d'un mètre. Le document donnait son point de vue sur les documents suivants. Le second document commençait par une vue d'ensemble courte sur le sensing inertiel et les orientations technologiques en cours. Les débats sur le développement technologique des accéléromètres et des gyroscopes ont été présentés, l'accent étant particulièrement mis sur la conception et les performances des Gyroscopes à laser Périphériques, des gyroscopes à Fibres Optiques et des capteurs MEMS. Le troisième document fournit une vue d'ensemble des principaux éléments de calcul associés aux centrales inertielles liées. Un système de positionnement relatif précis, fonctionnant à l'aide d'un enregistreur de données L1 GPS miniaturisé et autonome, est détaillé dans le quatrième document. Le cinquième document s'intéresse aux architectures d'intégration INS/GPS comprenant les configurations « légèrement couplé », « fortement couplé » et « profondément intégré ». Les avantages et les désavantages de chaque niveau d'intégration sont examinés. Dans le sixième et dernier document du premier jour, les trois principales architectures des systèmes INS/GPS examinées dans le document précédent ont été comparées suivant leurs performances dans divers scénarios de missions.

Le deuxième exposé mettra l'accent sur les dernières tendances en matière de technologies destinées à naviguer dans des environnements difficiles, urbains, intérieurs, ou souterrains, là où les récepteurs GPS habituels ne fonctionnent pas. On décrira les technologies alternatives de navigation utilisant l'optronique, parmi lesquelles les INS hybridés avec optique et ladar. Le dernier exposé sera consacré à la fusion de multi-capteurs pour la navigation en milieux difficiles. La présentation sera faite d'une approche générique de fusion de multi-capteurs, ainsi que sa simulation et ses résultats expérimentaux.